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TECHNICAL NOTE 4015

THEORETICAL AND EXPERIMENTAL INVESTIGATIONS
OF DELTA-WING VIBRATIONS

By Edwin T. Kruszewski, Eldon E. Kordes,
and Deene J. Weidman

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SUMMARY

The results of some theoretical and experimental investigations of delta-wing vibrations are discussed.

Nodal-line patterns and frequencies of a 45° built-up thin-skin delta-wing specimen obtained experimentally are compared with those calculated by two analytical methods - the idealized-structure type of method as described by Levy and a limited-deformation type of method proposed by Stein and Sanders. It is shown that when the effects of transverse shear are included into the Levy approach the agreement between calculated and experimental frequencies is exceptionally good.

Experimental nodal-line patterns and frequencies for a 60° thick-skin delta wing are also shown.

INTRODUCTION

The prediction of the vibrational characteristics of aircraft structures is a problem of importance to the designer of high-speed aircraft. As was discussed in reference 1, methods of predicting modes and frequencies for the large-aspect-ratio box-beam type of structure are very successful. However, for low-aspect-ratio or delta wings, the problem is still of particular concern because of the analytical difficulties involved in predicting their stiffness characteristics.

An experimental investigation of the modes and frequencies of two large-scale built-up delta-wing specimens has recently been completed. The results of this experimental investigation are being used to evaluate theoretical methods of deflectional analysis. This paper will deal with the findings of this evaluation.

DISCUSSION

One of the delta-wing specimens used in the experimental investigation is shown in figure 1. It is a built-up large-scale 45° delta with a span of 18 feet 8 inches, a midchord of 8 feet, and a uniform carry-through section of 2 feet 8 inches. The wing is uniform in depth in the chordwise direction but varies in depth in the spanwise direction from $5\frac{1}{2}$ inches at the carry-through section to $1\frac{3}{4}$ inches at the tip. The covers are made up of a thin sheet stiffened by spanwise stringers. In order to facilitate construction, the stringers were placed on the outside of the covers. The internal construction consisted of four spanwise spars and a bent leading-edge spar with light streamwise ribs spaced at close intervals. A detailed description of the stiffness properties and weight distribution of the specimen is given in reference 2.

A general view of the vibration test setup is shown in figure 2. The delta wing is hung vertically by flexible aircraft cables from the gallows shown in the figure. The specimen was vibrated in the horizontal direction so that the wing could be considered to be essentially free-free. The vibrations were produced by four electromagnetic shakers (three of which can be seen in fig. 2). The mode shapes were obtained from pickups mounted at the intersection of the spars and ribs while the node-line locations were determined with a portable probe pickup. A total of 10 natural modes of vibration was established, five symmetrical and five antisymmetrical, with frequencies ranging from 43 to 216 cycles per second. Detailed descriptions of the vibration tests are given in reference 2.

In recent years a variety of methods of load deflectional analysis for low-aspect-ratio and delta wings has been proposed. (See, for example, refs. 3 to 6.) Two of these methods have been used for calculating the modes and frequencies of this specimen. One was described by Levy in reference 3 and the other was developed by Stein and Sanders in reference 4. Although both of these methods were discussed in detail in references 3 and 4, a recapitulation is thought to be worthwhile. Both of the methods are an influence-coefficient type of procedure; that is, the vibrational problem is set up through the use of static influence coefficients and the inertial characteristics of the structure. Furthermore, both methods neglect the effects of transverse shear.

The essential features of the two methods are shown schematically in figure 3. The Levy method deals with a simplified structure but allows arbitrary deflections of that structure. On the other hand, the Stein-Sanders method analyzes the actual structure but restricts the allowable deflection shape.

Consider first the Levy method. As shown in figure 3 the actual wing is idealized into a system of interconnecting beams and torque boxes. All the spanwise normal-stress-carrying material of the covers, both sheet and stringers, is concentrated into the spars of the idealized wing while all the chordwise normal-stress-carrying material is concentrated into the ribs. The shear-carrying capacity of the cover sheets is accounted for by torsion boxes in the spar-rib cells.

The stiffness influence coefficients for each component part of the idealized structure, that is, the spars, ribs, and torsion boxes, are superimposed to yield the stiffness influence coefficients of the complete structure. The flexibility influence coefficients are then obtained directly by inversion. Note that because of the nature of the idealization used, the Levy method is intended to be applied primarily to thin-skin structures, such as the particular 45° delta-wing specimen used in the experimental investigation.

The Stein-Sanders method deals with the deflections of the neutral surface of the actual wing. It is assumed that the chordwise variation of the deflection w is parabolic and can be expressed in the form shown in figure 3. In this case ϕ_0 , ϕ_1 , and ϕ_2 give the spanwise variation of the deflection, slope, and chordwise curvature at the trailing edge. Since the effects of transverse shear are neglected, the distortions of the various elements in the wing can be expressed in terms of the ϕ 's. Further by taking a number of stations along the wing and by going through a straightforward calculation, the values of the ϕ 's at the various stations can be expressed in terms of the loading at those stations.

Since the Stein-Sanders method deals with the actual structure, it should handle a thick-skin wing as well as a thin-skin wing. However, the restriction to parabolic deflections in the chordwise direction may lead to serious errors unless the center section is very stiff against chordwise bending.

The comparisons of the results of these two theoretical solutions and those obtained from the experimental investigation are shown in figure 4. In this figure the nodal-line patterns and frequencies are shown for the first five symmetrical modes.

As can be seen, the nodal-line patterns from the Stein-Sanders method agree quite well with the ones obtained experimentally. The frequency agreement, however, is poor; the errors ranging from 7 percent in the first mode to 38 percent in the fifth mode. On the other hand, the frequency agreement in the Levy method is much better. The largest error in the first four modes (which occurs in the third mode) is only $7\frac{1}{2}$ percent while the error in the fifth mode is 20 percent.

Some of the errors in the Stein-Sanders method are undoubtedly due to the assumption of parabolic chordwise deformation. This particular specimen had no extra chordwise stiffening in the center of the wing, such as would be furnished by a fuselage, for example. On the other hand, as previously noted, the Levy approach should be applicable to this specimen because of its relatively thin covers. Therefore, it is not too surprising that the Levy method gives better results.

Although the Levy method does give better results, the results are still somewhat unsatisfactory, especially for the fifth mode. For this reason, an investigation of the influence of transverse shear, which was neglected in the preceding calculations, was undertaken. This investigation dealt solely with the Levy method for which an approximate correction for transverse shear could be made with little additional labor. The effects of the shear deformations of the webs were simply included in the stiffness-coefficient calculations of the individual spars and ribs, but the torsion-box coefficients were left unchanged.

The results from this recalculation are presented in table I which summarizes the frequencies obtained by the different methods for the first five symmetrical modes. The frequencies as obtained experimentally are tabulated in the first row. The corresponding frequencies as calculated by the Stein-Sanders method and by the Levy method without shear are shown in the second and third rows, respectively. Shown in the fourth row are the results from the Levy method with the effects of transverse shear included. The frequencies shown in the last row will be discussed a little later in the paper. As can be seen, the frequencies calculated by the Levy method with shear are in excellent agreement with the experimental frequencies. The largest error, which occurred in the fourth mode, being slightly less than 4 percent. Furthermore, a comparison of the frequencies in the third and fourth rows shows that the effects of transverse shear can be appreciable; the largest effect being in the fifth mode where the inclusion of transverse shear causes an 18-percent reduction in the calculated frequency. The effects of transverse shear on the calculated nodal-line patterns were slight. The changes that did occur, however, tended to improve the comparison between theory and experiment.

Although only the symmetrical modes of vibration have been discussed, the antisymmetrical results indicate the same conclusions; that is, the Levy method predicts the modes and frequencies of thin wings with thin skins such as the 45° delta wing tested with more accuracy than the Stein-Sanders method and, secondly, the effects of transverse shear, which can be appreciable, are easily and accurately incorporated into the Levy method.

Now to digress a little, consider the frequencies shown in the last row of table I, which were calculated from influence coefficients determined experimentally. These results are of interest because a popular

method of obtaining frequencies is to measure influence coefficients either on a model or a full-scale structure and then to use these coefficients in a vibrational analysis. For the delta-wing specimen, this particular method yields results which are also very good. However, it must be remembered that the influence coefficients were measured on the actual wing; therefore, no errors due to modeling are involved. The advantage of the purely analytical method in the design stage is obvious.

An investigation of the vibrational characteristics of another delta-wing specimen of entirely different type of construction is being carried out. Although the calculations are not complete, the experimental information obtained should be of interest. A sketch of this specimen is shown in figure 5. It is a built-up 60° delta wing with a span of 8 feet and a midchord of 7 feet 4 inches. A chordwise cross section of the wing is shown in the figure. The covers are plates with integral waffle-like stiffening and are fastened to relatively light spars and ribs.

The sketches of the experimental nodal lines of the 60° delta wing for the first six modes (3 symmetrical and 3 antisymmetrical) are shown in figure 6. The corresponding natural frequencies are noted at the bottom of each sketch. The frequencies range from 82.5 cycles per second in the first mode (first antisymmetrical) to 207.9 cycles per second in the sixth mode (third antisymmetrical). Only six modes of vibration were obtained due to excessive panel vibrations of the covers. It is also believed that these panel vibrations could be partly responsible for the asymmetry of the nodal-line patterns.

The specimen is representative of thick-skin construction and thus will furnish an acid test for the Levy method. Although calculations have not been made, it is believed that the Levy method with correction for transverse shear will not predict the frequencies of the 60° delta wing as well as it predicted the frequencies of the 45° delta wing. The principal source of error in the Levy method is the neglect of the influence of the Poisson's ratio effect on the interaction of the chordwise and spanwise stresses. This effect, which is important in thick-skin wings, cannot be readily included into the Levy approach.

CONCLUSIONS

Comparisons of experimental and calculated modes and frequencies of a delta-wing specimen have shown that the idealized-structure type of method as proposed by Levy gives excellent results for thin-skin wings provided that corrections are made for the effects of transverse shear. The limited deformation type of method proposed by Stein and Sanders is

apparently inapplicable to low-aspect-ratio wings when the center section is not very stiff against chordwise bending.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 7, 1957.

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TABLE I
COMPARISON OF EXPERIMENTAL AND CALCULATED FREQUENCIES
FOR SYMMETRICAL MODES

Frequency determined by -	Frequency, cps, for -				
	1st mode	2d mode	3d mode	4th mode	5th mode
Experiment	43.3	88.8	122.8	164.2	179.7
Stein-Sanders method	46.4	105.3	150.0	202.0	248.0
Levy method (without shear)	44.6	94.7	132.0	172.0	216.0
Levy method (with shear)	42.8	88.9	120.1	158.0	184.0
Experimental influence coefficient . .	43.1	83.0	118.0	146.0	172.0

45° DELTA - WING SPECIMEN

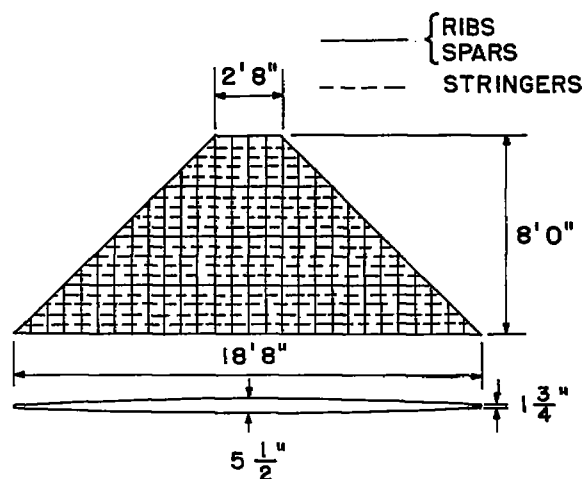


Figure 1

VIBRATION-TEST SETUP OF DELTA-WING SPECIMEN

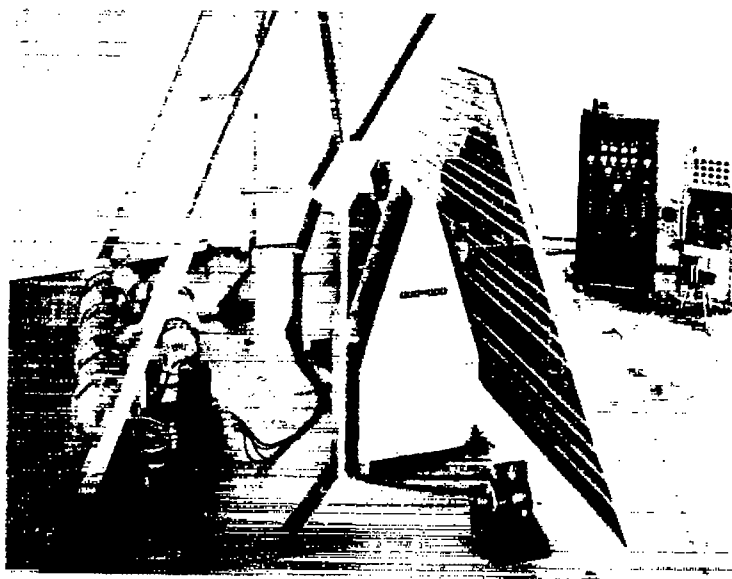


Figure 2

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THEORETICAL APPROACHES CONSIDERED

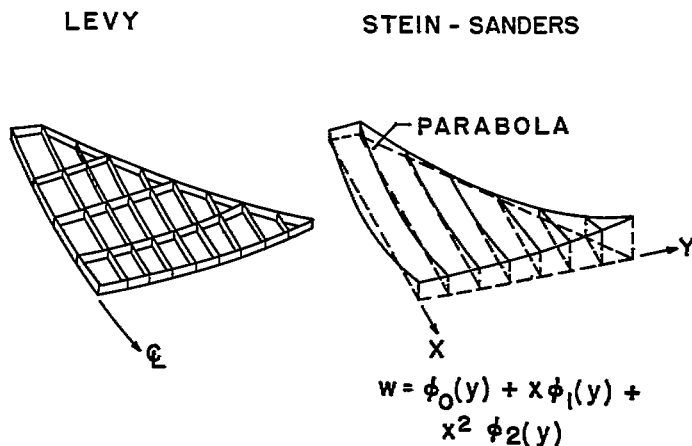


Figure 3

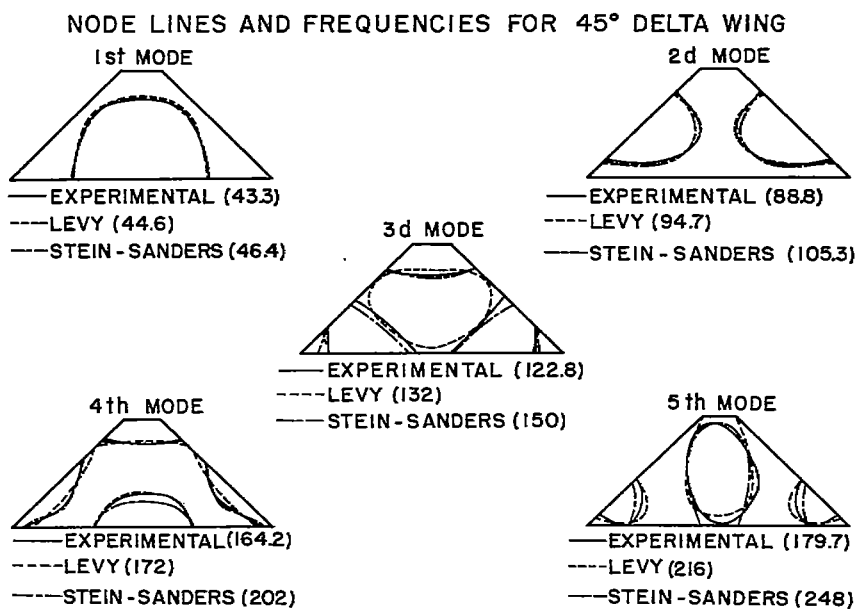


Figure 4

60° DELTA -WING SPECIMEN

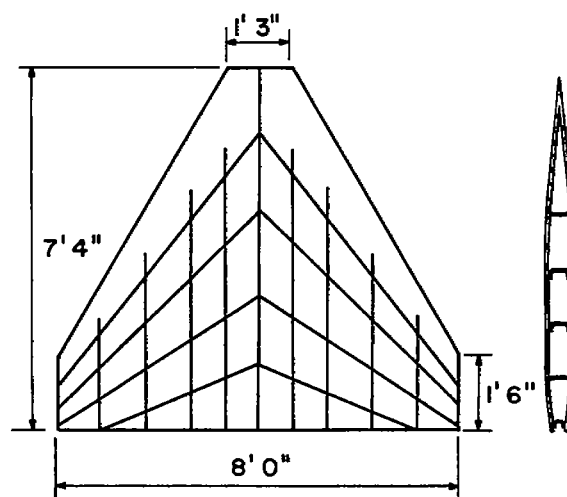


Figure 5

NODE LINES AND FREQUENCIES OF 60° DELTA WING

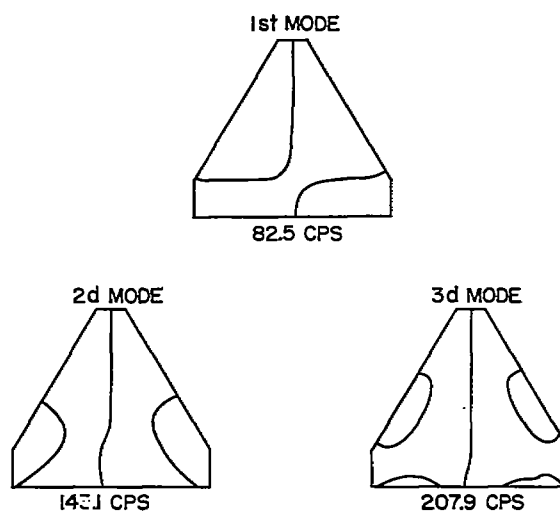
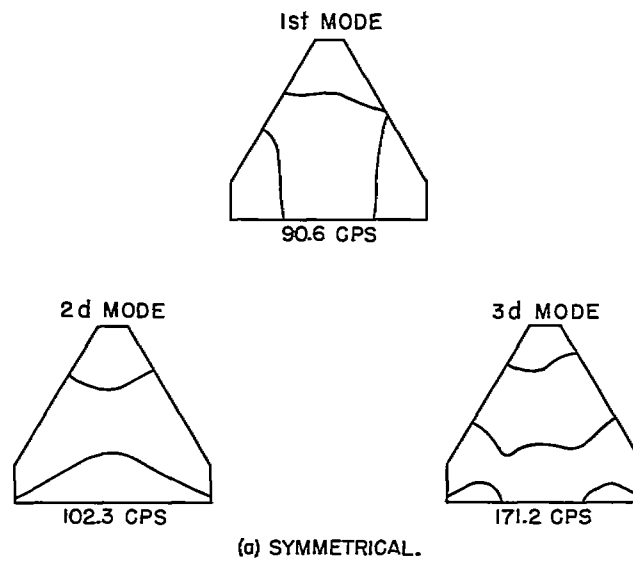


Figure 6